LF/VLF Waveform Classification

Intl Conf. Atmospheric Electricity, June 2003
LA-UR-03-2078

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Abstract

The Los Alamos Sferic Array network of fast electric-field-change meters has geolocated over seven million lightning events in the United States (primarily near New Mexico and Florida) from 1998 to the present. Previous work has included the automated identification of cloud-to-ground lightning and a specific type of intracloud lightning (compact intracloud discharges or narrow bipolar events). The cloud-to-ground and narrow bipolar events identified represent approximately half of the entire seven million events. We are extending the waveform identification to include the identification of general intracloud lightning activity, leader activity preceeding cloud-to-ground discharges, sprite producing positive cloud-to-ground discharges, improve cloud-to-ground identification, and better understand narrow bipolar events.

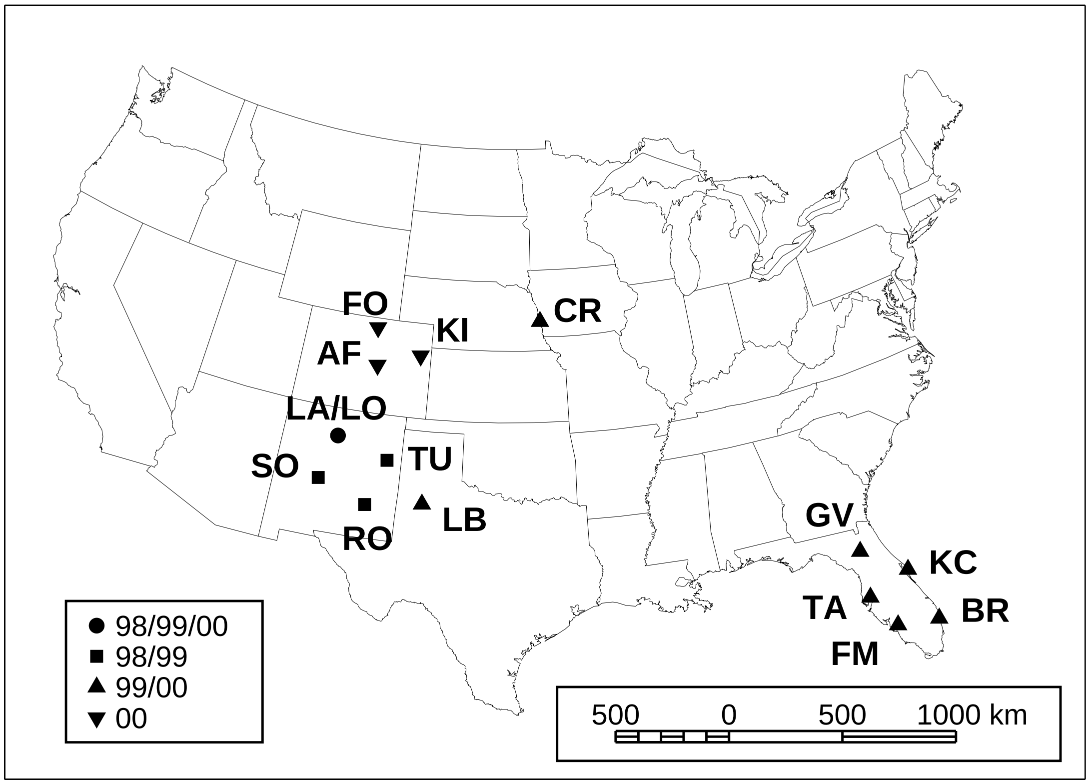
Motivation

The Los Alamos Sferic Array (LASA) is an array of electric field change meters operated as an experimental system for ground support of satellite observations of lightning. We now have a data set of over seven million multi-station, differential time-of-arrival located events. LASA was originally used primarily for ground-truthing the FORTE satellite observations of specific type of intracloud lightning activity called Compact Intracloud Discharges (CIDs) [Smith *et al.*(1999)]. The LASA observed LF/VLF signature of CIDs has been called Narrow Bipolar Events (NBEs). The signature of CIDs observed in the VHF by FORTE were termed Trans-Ionospheric Pulse Pairs (TIPPs) [Massey *et al.*(1998)]. In support of GPS satellite observations of both CID and cloud-to-ground (CG) lightning, LASA's classification routines were expanded to identify both CIDs and CGs. Approximately half of all LASA events are identified as either CIDs or CGs.

Motivation

The basis for this study was to quantify the portion of the unidentified lightning events that were non-NBE IC discharges. At LF/VLF, ICs are not as well characterized as CGs, primarily because CGs are a much stronger radiator. Therefore, large geographical scale IC studies have not been performed. [Mackerras *et al.*(1998)] report IC rates based on sensors with a range of detection of only $\sim$ 14 km. IC activity is of interest for several reasons: First, optical satellite observations may be more sensitive to ICs than CGs [Light *et al.*(2001)]. Second, to study thunderstorm convective state based on the ratio of IC and CG lightning [Williams *et al.*(1989), Boccippio *et al.*(2001)]. The difficulty in large-scale, ground-based observations of ICs, and the fairly long range observation capabilities of LF/VLF systems motivated the routine identification of IC lightning by LASA.

Los Alamos Sferic Array



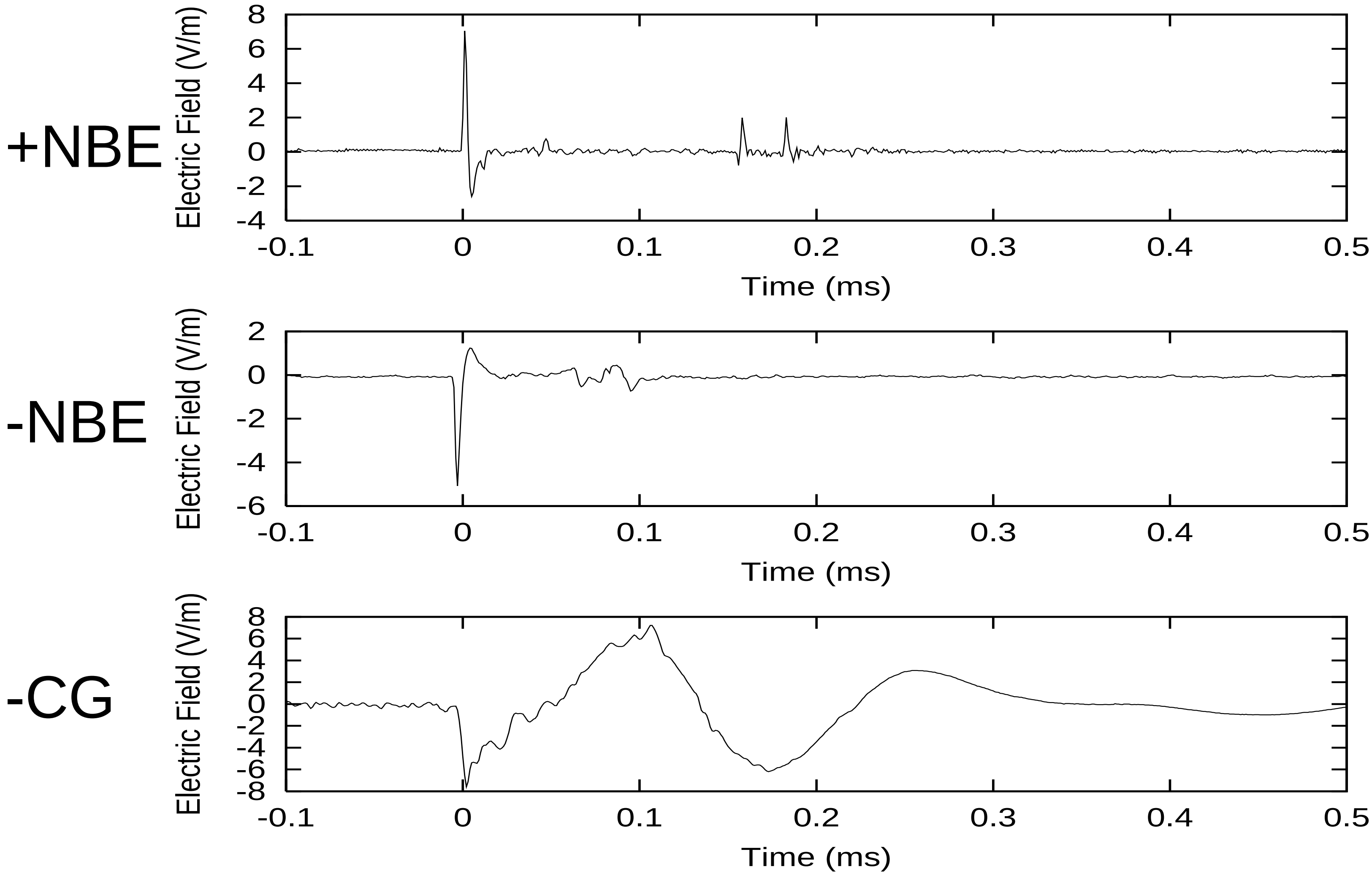
The Los Alamos Sferic Array (LASA) is an array of up to eleven LF/VLF electric field change meters which have been relocated to support various synergistic campaigns since 1998. The locations are illustrated in the map at left. The field change meters use an amplitude threshold triggering system to record the vertical electric field, digitized at 1 MHz with 12 bit resolution.

Los Alamos Sferic Array

Each LASA station utilizes GPS receivers to provide absolute event time tagging with an accuracy of better than 2 μs. Using differential time of arrival methods for events recorded at multiple stations, discharges are geo-located. Most commonly, LASA records are 8 ms in duration including 2 ms of pre-trigger data. Based on initial investigation into intracloud and leader LF/VLF radiation, 80 ms and 1 s records were collected by LASA stations to provide stroke context. [Smith *et al.*(2002)] describe the operation and instrumentation of LASA and characterize the accuracy of LASA geolocation.

LASA is a system which provides ground truth for satellite observations of intracloud lightning activity (specifically CIDs) over a large spatial region (1000 km in radius or more). In part, this study is to improves the LASA data set to include non-NBE intracloud activity.

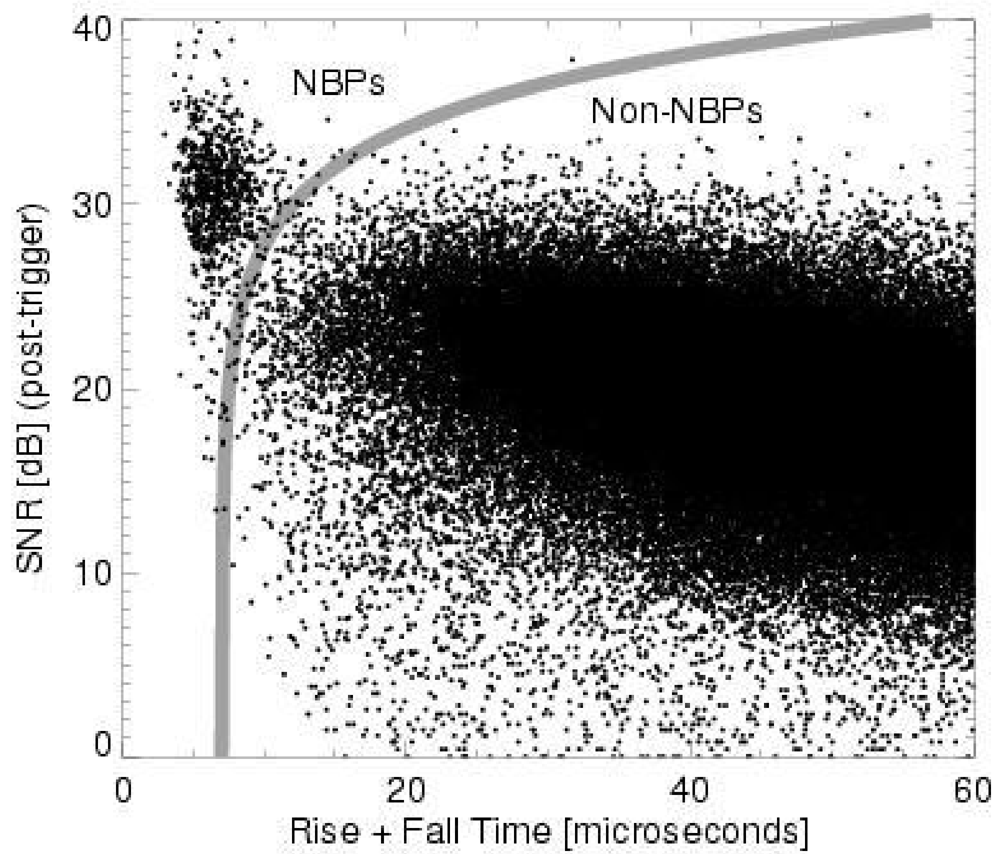
LASA NBE/CG Discrimination, 1



LASA NBE/CG Discrimination, 2

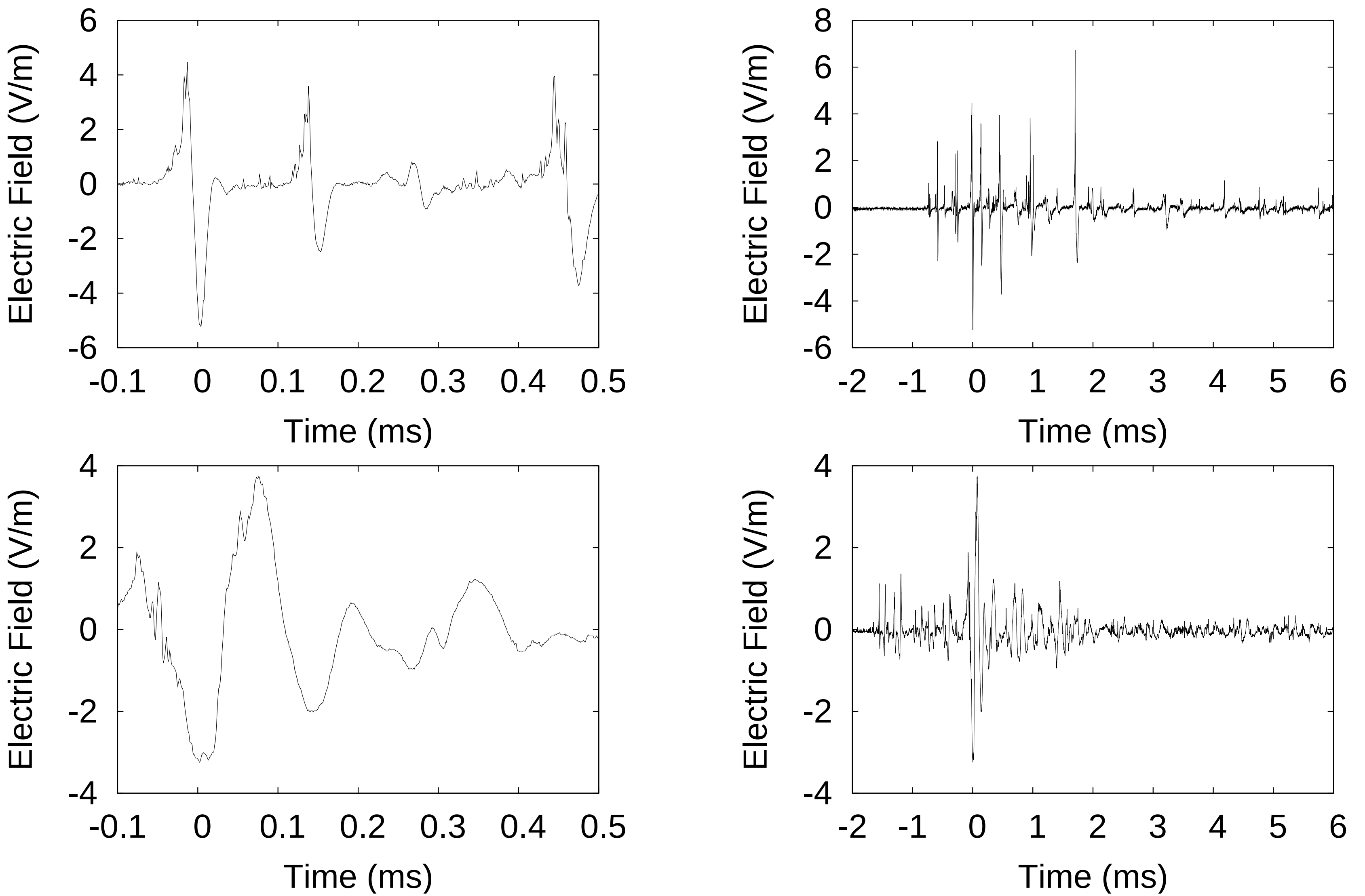
The figure above shows three waveforms recorded by LASA stations. The upper panel is a typical +NBE waveform recorded by a LASA station. The two pulses at $\sim$ 0.2 ms are the ionospheric and ground-ionospheric reflections of the signal. The middle panel is a typical -NBE event with two reflections appearing at $\sim$ 0.1 ms after the initial burst of radiation. The bottom panel is a typical -CG LF/VLF waveform. There is some low amplitude leader activity preceding the large negative excursion which is the return stroke. The fall-time, or return from the minimum to zero, is nearly 50 μs. The CG events are the most common type recorded by LASA, while the NBEs are of great interest because the are the LF/VLF signature of CIDs, one of the strongest natural sources of VHF emissions, and therefore of interest for FORTE and GPS lightning observations.

NBE Identification

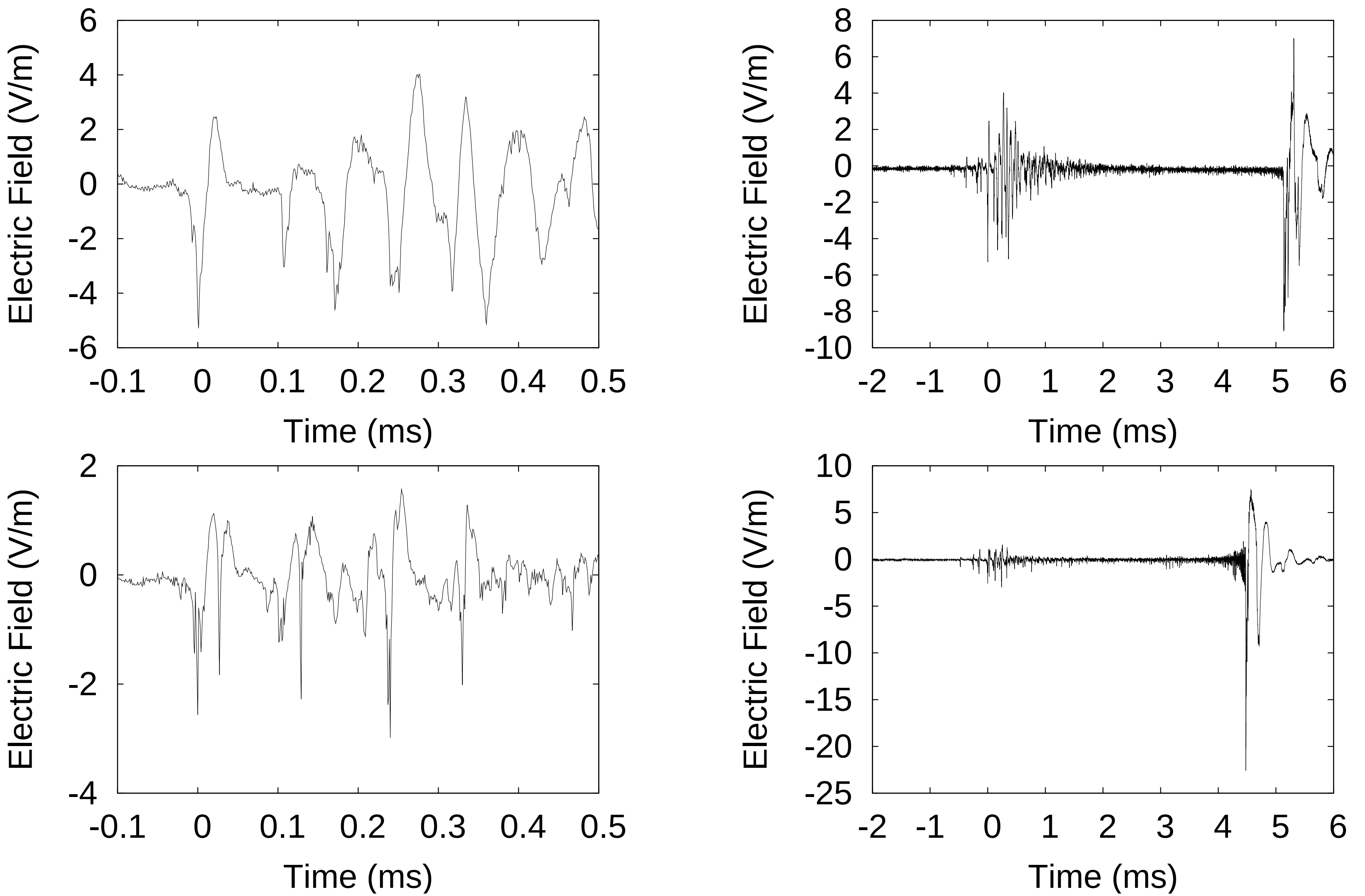


Narrow Bipolar Pulses (NBPs) are distinct based on the relative lack of neighboring radiation (or the relative isolation of the pulse) and the narrow nature of the signature (the rise time and the fall time of the waveform). As illustrated at right, the NBPs are tagged in the LASA database based on these two parameters. In comparison, the classification of CG events is based solely on the relatively slow (greater than 30 μs) fall time.

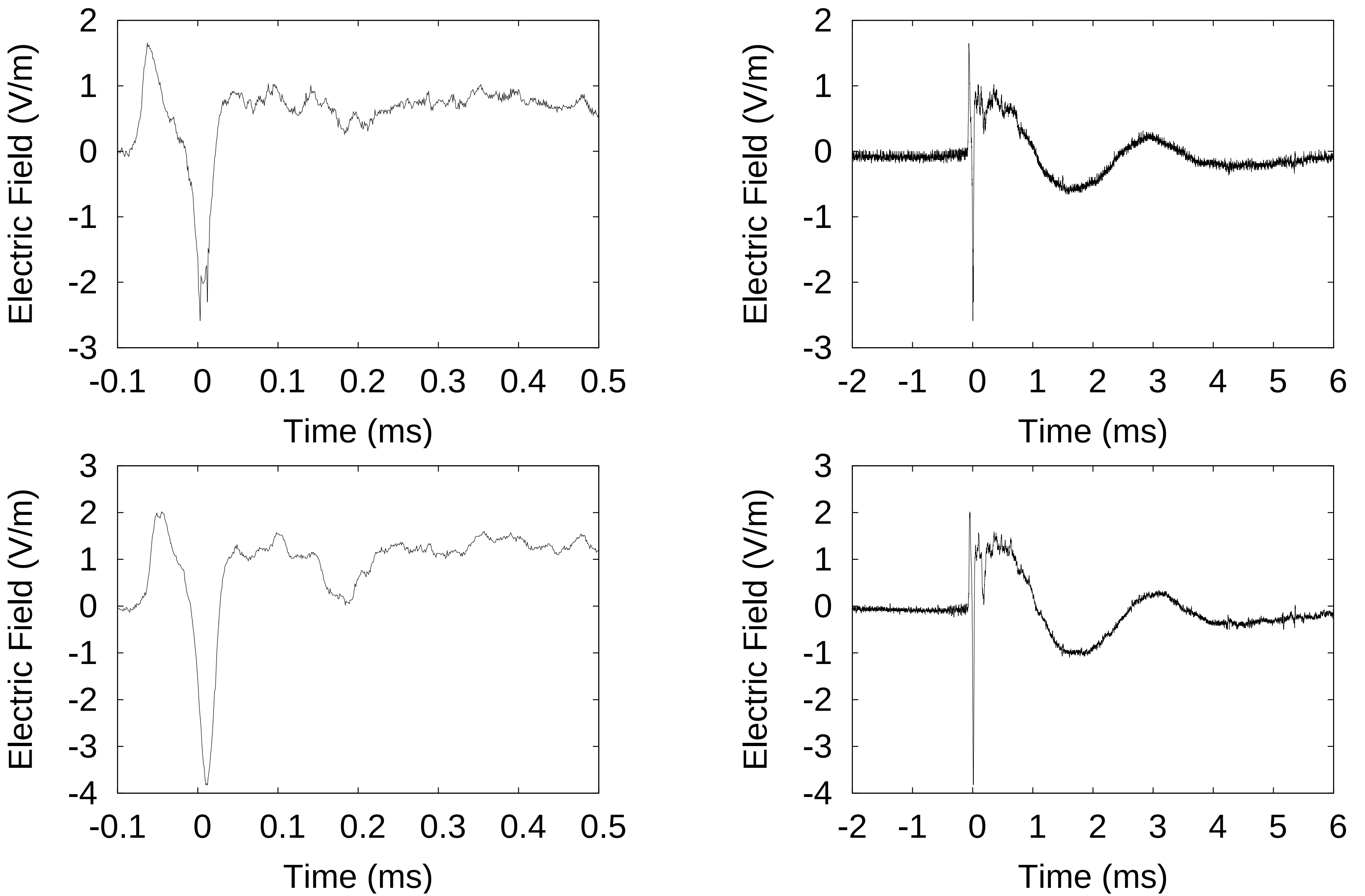
IC Waveform Examples



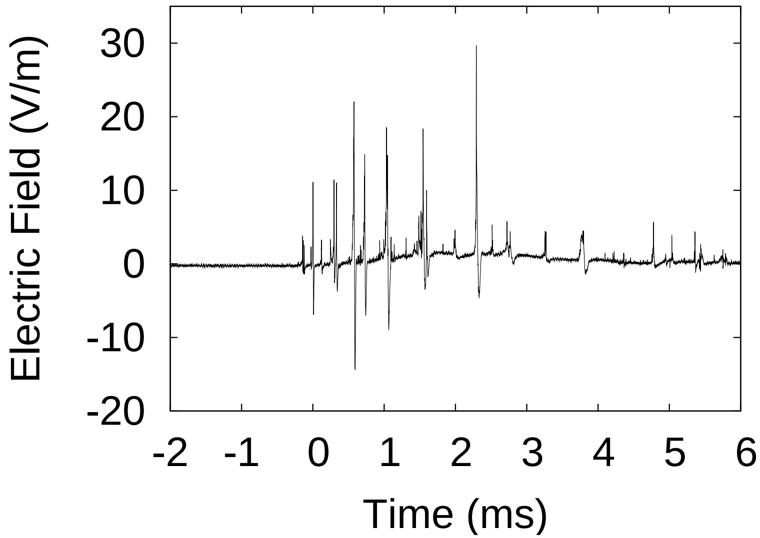
Leader Waveform Examples

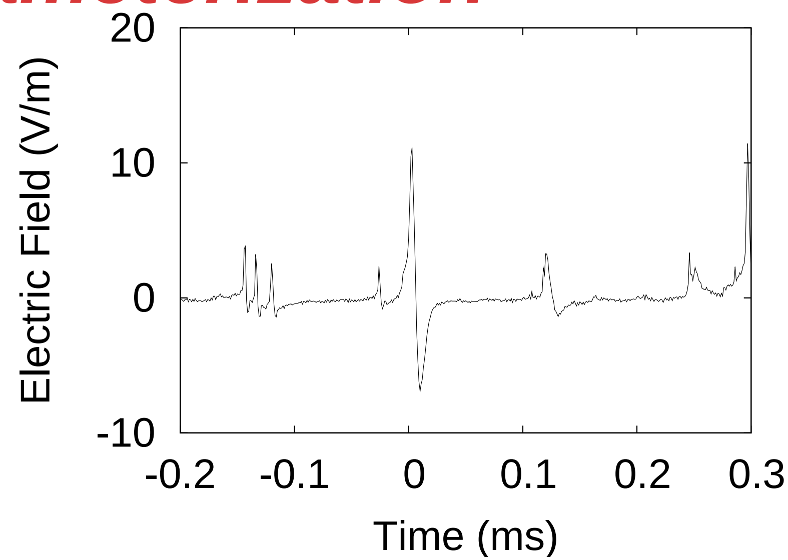


+CG/Sprite Waveform Examples



Waveform Parameterization



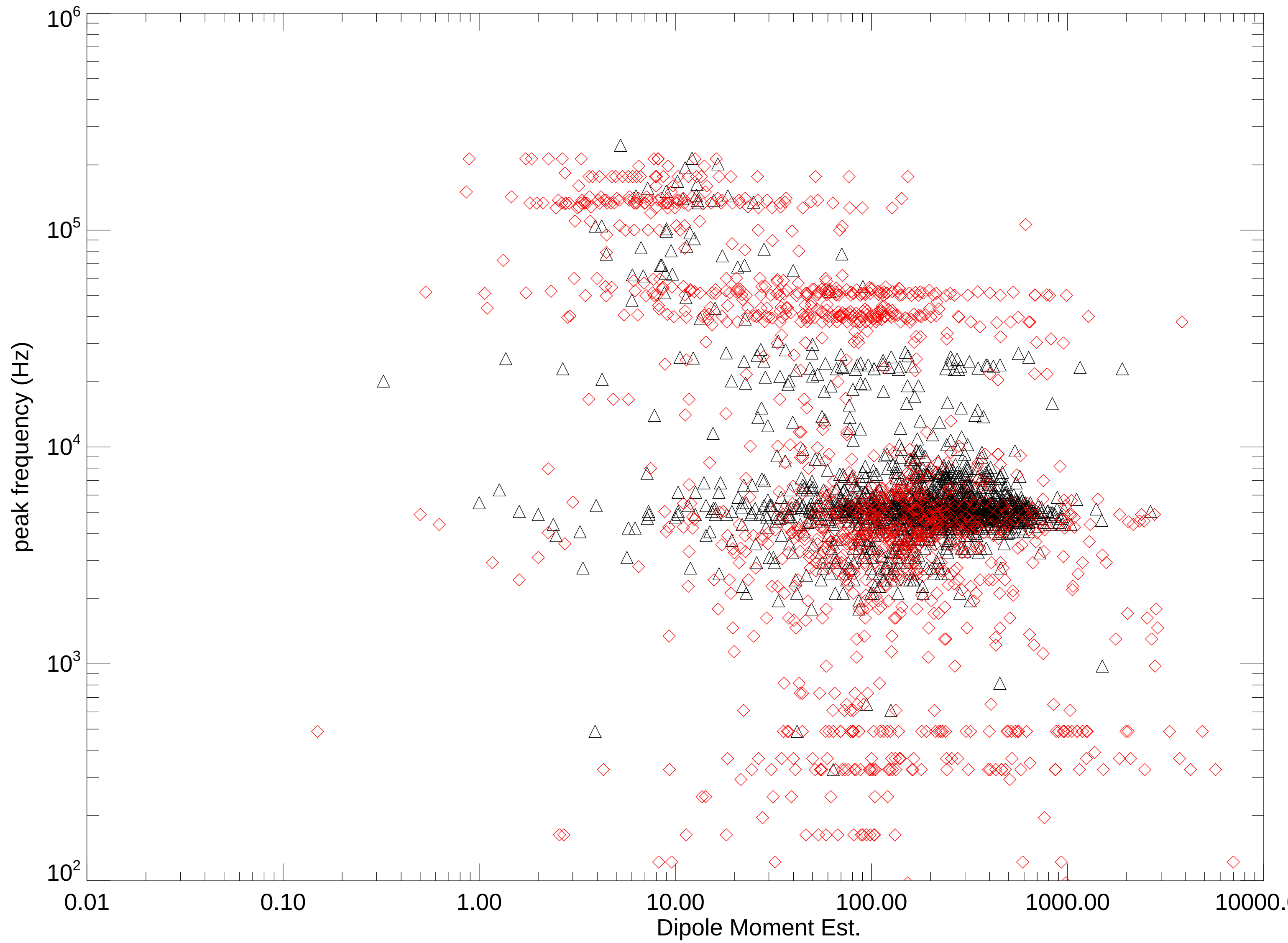


Trigger Polarity - polarity at the trigger point [i]	P
Slope Polarity - polarity of [i-1] - [i]	P
Peak Polarity - polarity at max(abs(data))	P
Event Polarity - polarity at event (xcorr between stations)	P
Event Peak Polarity - polarity at max (+/- 30 us of event)	P
Saturated ?	N
Absolute minimum value (V)	-1.319
Absolute maximum value (V)	2.793
Index of absolute minimum value	593
Index of absolute maximum value	2293

Waveform Parameterization

Minimum +/- 30 us of event (V)	-0.335
Maximum +/- 30 us of event (V)	2.793
Index of minimum +/- 30 us of event (V)	2323
Index of maximum +/- 30 us of event (V)	2293
Rise Time (inverse slope from max to 10% max)	21.8 us
Fall Time - max to next zero crossing)	26 us
FWHM around event max	6
Isolation pre - (data^2 +/- 5 us) / (data^2 - 6 us)	815
Isolation post - (data^2 +/- 5 us) / (data^2 +)	8.78
No. -/+ 'spikes' - excursions $>$ 50% min/max	2, 8
Index of first -/+ 'spike'	586, 571
Index of last -/+ 'spike'	1062, 2291
Integral from 10% to zero crossing	29.9
Double Integral from 10% to zero crossing	686
Double Integral from 10% to 100 us	2140
Double Integral from 10% to 500 us	24700
Duration of above Integrals	39, 100, 500
Peak Frequency of FFT +/- 1 ms around trigger	19.5 kHz

Peak Frequency vs. Dipole Moment Change



Acknowledgements

This work was performed under the auspices of the United States Department of Energy. LANL personnel who made significant contributions include A Jacobson, M Pongratz, X M Shao, M Carter, D Roussel-Dupré, and R Sheldon. We thank the many hosts of LANL sferic array stations, without whom this research would not be possible. M Heavner acknowledges many fruitful discussions with C Talus.

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